100 TeV MUON COLLIDER + VLHC

VLHC

+

VLMC

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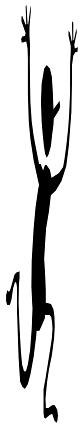
TOPICS

- INTRODUCTION & MOTIVATION
- NEUTRINO RADIATION => ISOLATED SITE
- TECHNICAL ISSUES FOR VL**M**Cs
- 140 TeV MU-P COLLIDER
- MUON ACCELERATION AS 1/2-ENERGY PROTON INJECTOR

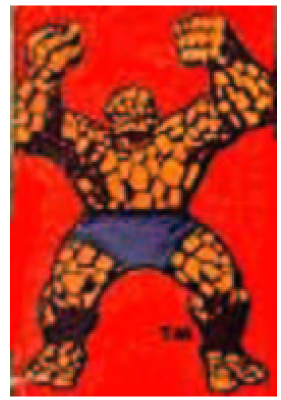
Extend the energy frontier!

LONG-TERM POTENTIAL GAINS FROM A 3rd PROJECTILE



Electrons
are too light

Discovery reach
of a few TeV ?



Protons are composite
& strongly interacting

Discovery reach of
some 10's of TeV ?

Add Muons,
though unstable

Discovery reach of
~100 TeV (circular)?
~1 PeV (linear)???

$m_\mu \sim 206 \times m_e$
$\mu \to e\nu\nu$
$\tau_\mu = 2.2\ \mu s$

Muons have the highest potential discovery reach, using clean lepton-lepton collisions, so the successful development of muon collider technology will maximize the long-term potential of experimental HEP.

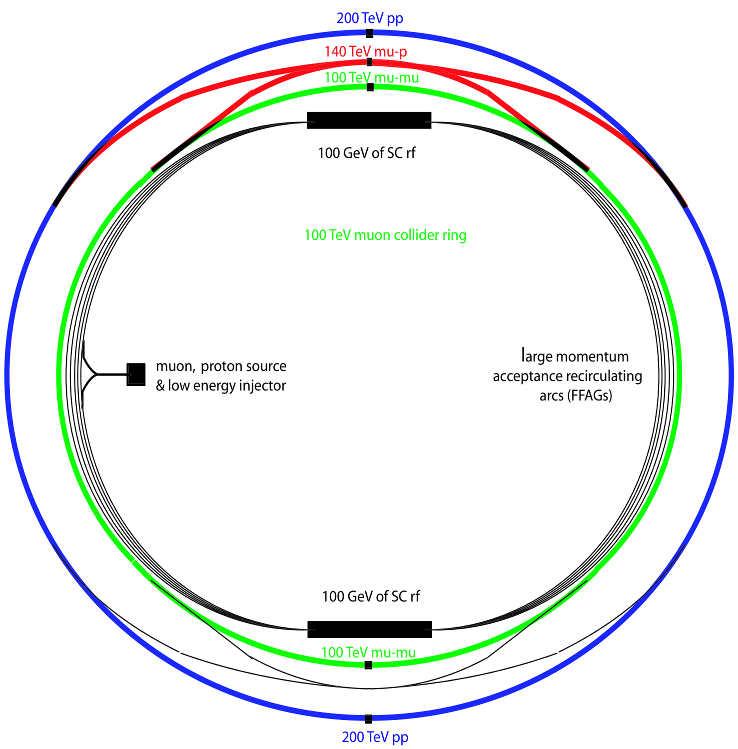
PLAUSIBLE NEW FRONTIER LAB.: VLHC + VLMC

Neutrino radiation => new, very isolated lab. for high luminosity Very Large Muon Collider (VLMC).

On balance, technical difficulties not much worse than for lower energy muon colliders.

(slightly less cooling needed; recent 30 TeV final focus design by Raimondi)

Schematic Layout showing Acceleration,
Muon Collider, Proton Collider & mu-p Collider

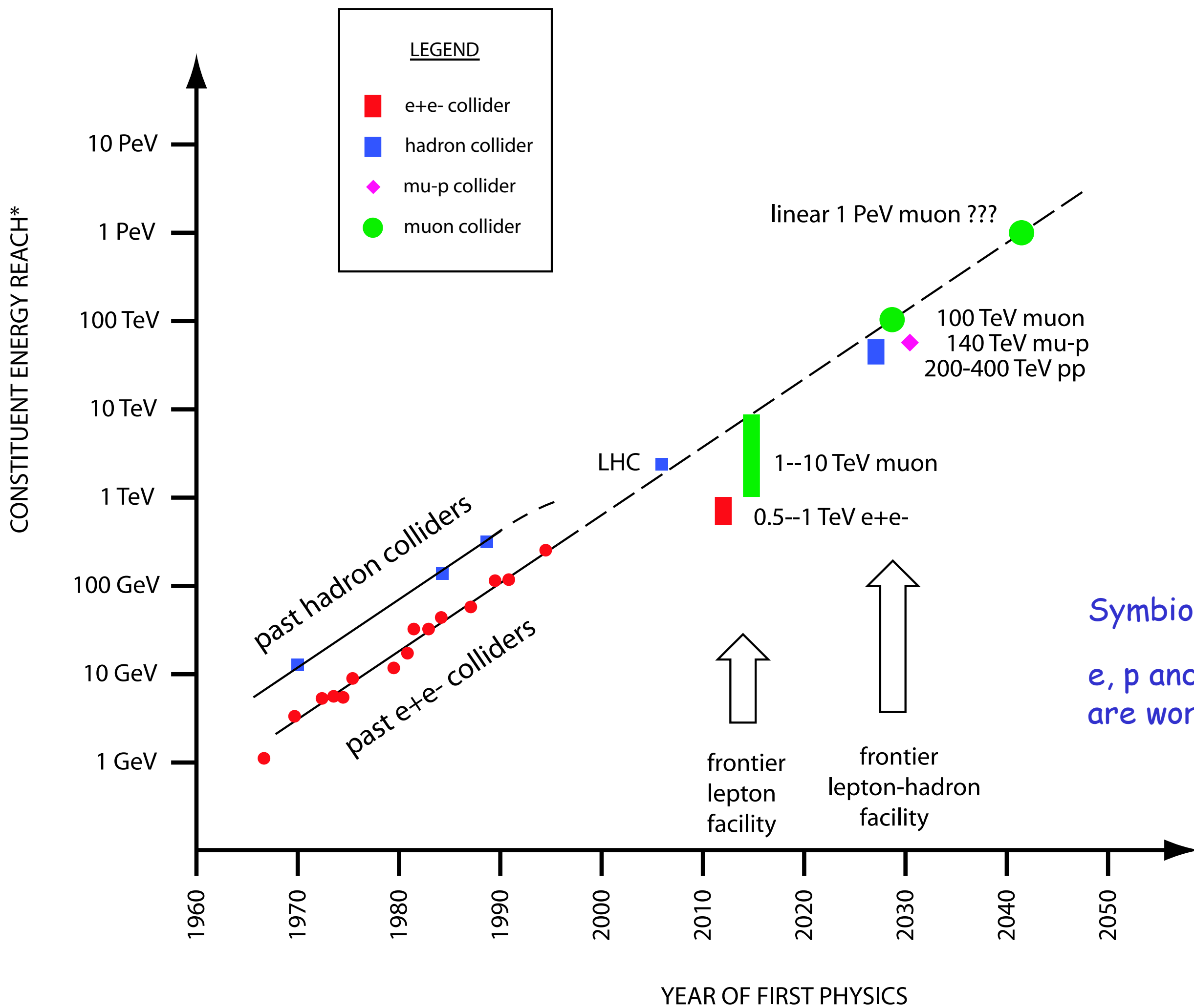


VLMC + VLHC symbiosis:

- ✓ common magnet R&D
- ✓ same tunnel, or side-by-side
- ✓ common acceleration to ~50 TeV/beam
  - ➢ full energy for muon collider
  - ➢ ~½ energy for hadron collider
- ✓ mu-p collisions at E_{CoM} ~ 140 TeV

(SEE STRAW-MAN VLMC PARAMETER SET @ 100 TeV)

THERE ARE PLAUSIBLE PATHS TO A VLMC+VLHC FACILITY ...



Symbiotic!

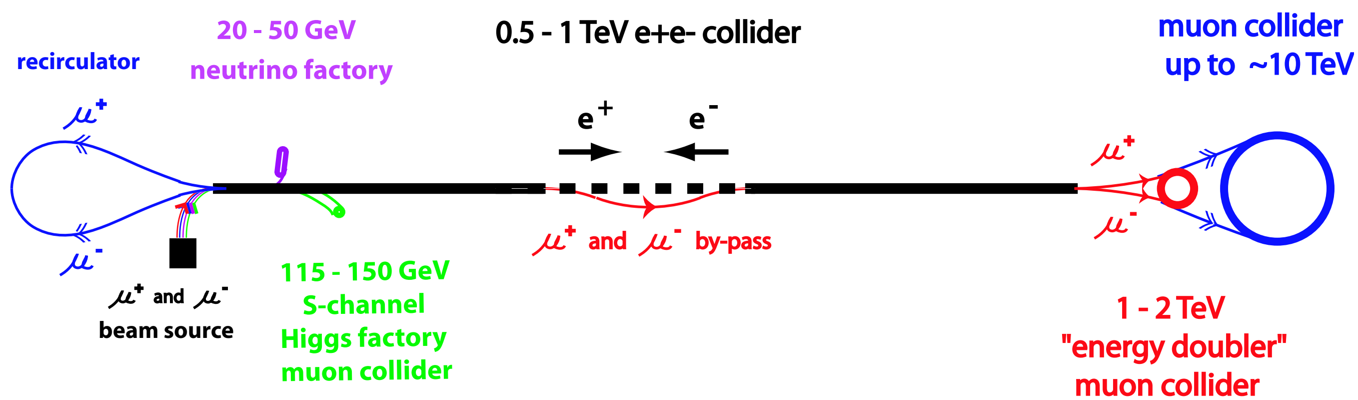
e, p and μ technologies are working together

* assume constituent energy reach for hadrons = 1/6 x CoM energy

SYMBIOTIC FACILITY: LINEAR e^+e^- COLLIDER + MUON COLLIDER

First discussed by D. Neuffer, H. Edwards & D. Finley in Proc. Snowmass'96

Works better for larger, superconducting cavities ("TESLA")



CHALLENGES: **a)** design of (very) high performance muon cooling channel, **b)** integration into e+e- collider design, **c)** major design constraints & luminosity cap to greatly suppress neutrino radiation

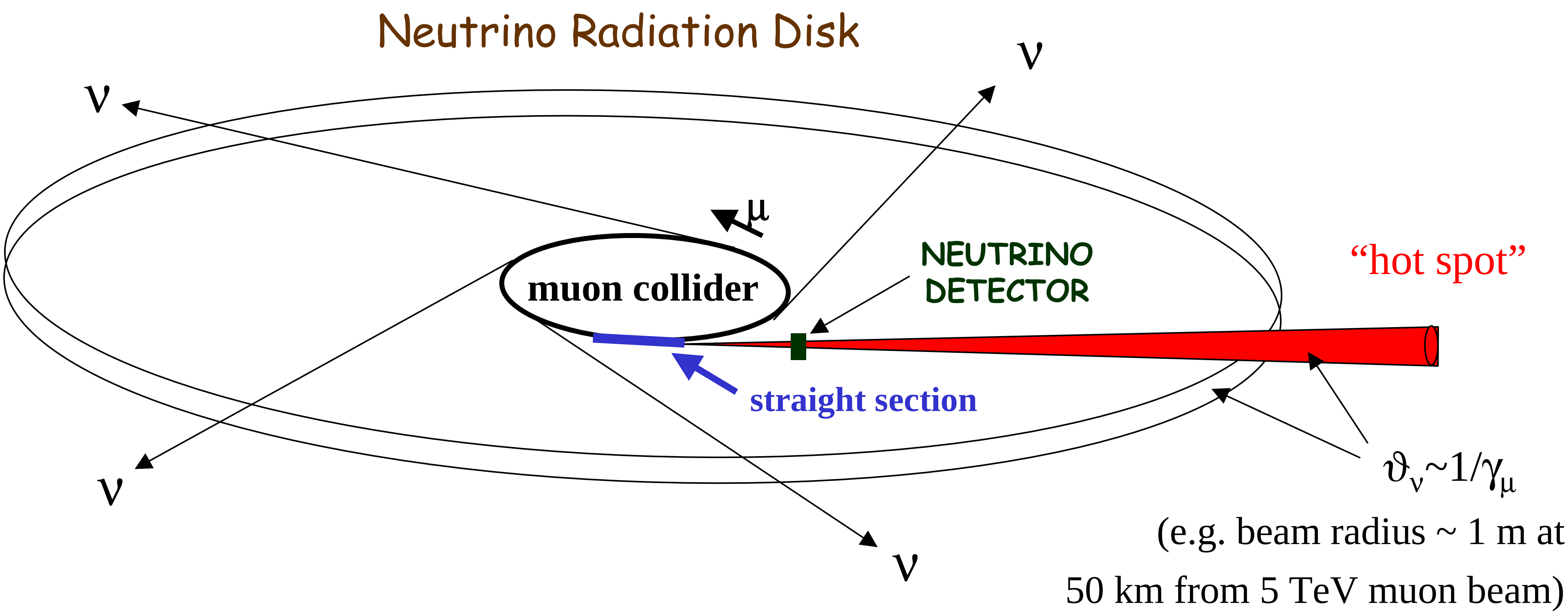
(worst case $<$ 10^{-2} mSv/yr ~ 0.003 x U.S natural bgd. rad.)

POTENTIAL: $E_{CoM} \rightarrow 10\ \text{TeV}\ \text{with}\ \mathcal{L} \sim 1\times10^{34}\ \text{cm}^{-2}.\text{s}^{-1}$ (+ neutrino, s-channel Higgs factories)

HEP results (LHC, Tevatron, ν physics) will decide the actual add-ons: "Swiss army knife accelerator"

NEUTRINO RADIATION => ISOLATED SITE

NEUTRINO RADIATION

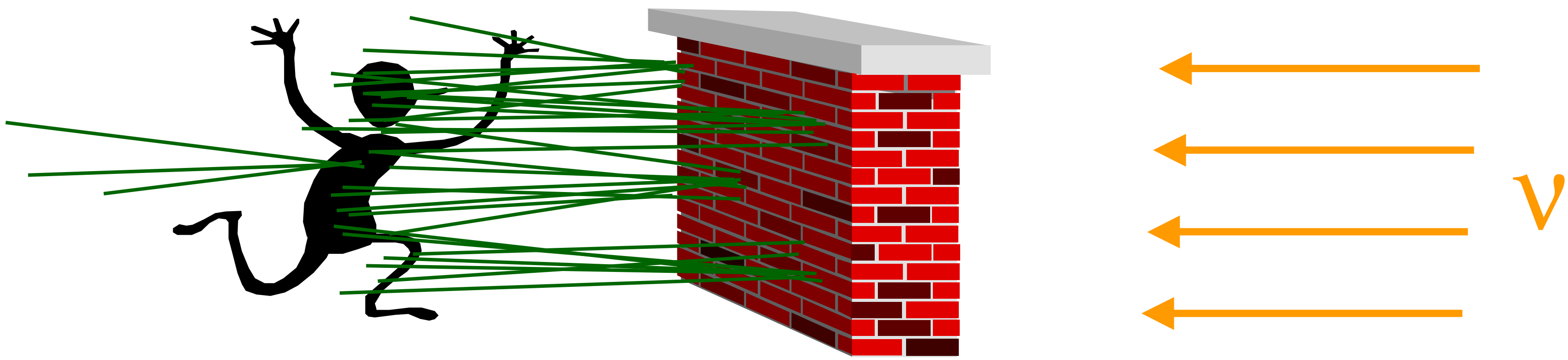


Extra Physics + extra hazards

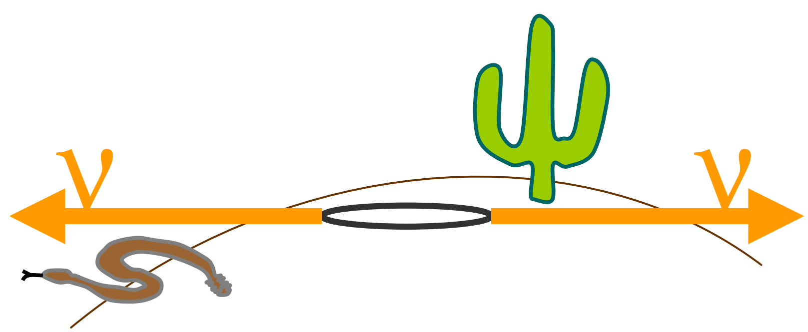
*ref. B.J. King, " Potential Hazards from Neutrino Radiation at Muon Colliders", **physics/9908017**; B.J. King, "Neutrino Radiation Challenges and Proposed Solutions for Many-TeV Muon Colliders", Proc. HEMC'99, **hep-ex/0005006**.

THE OFF-SITE RADIATION CONCERN

The hazard is charged particles from neutrino interactions in the surroundings ...

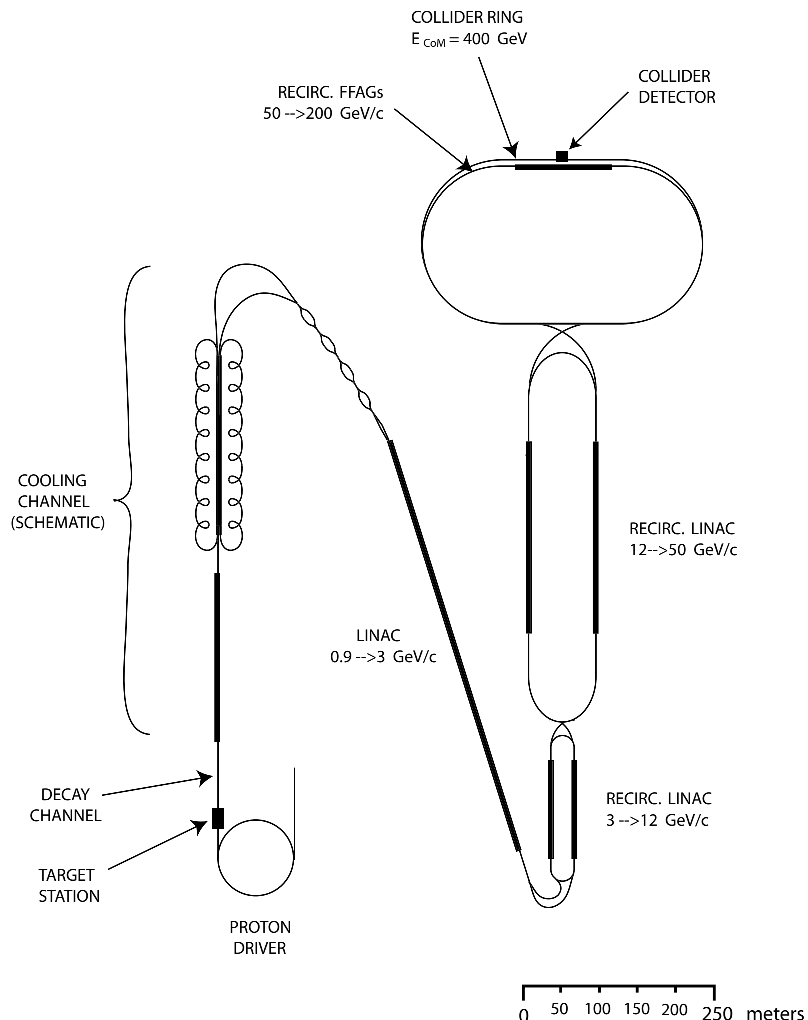


The predicted dose rises sharply with collider energy. A VLMC will need to be located at a very isolated site, e.g. a neutral site such as the Australian outback, and operated using a Global Accelerator Network.



TECHNICAL ISSUES FOR VLMCs

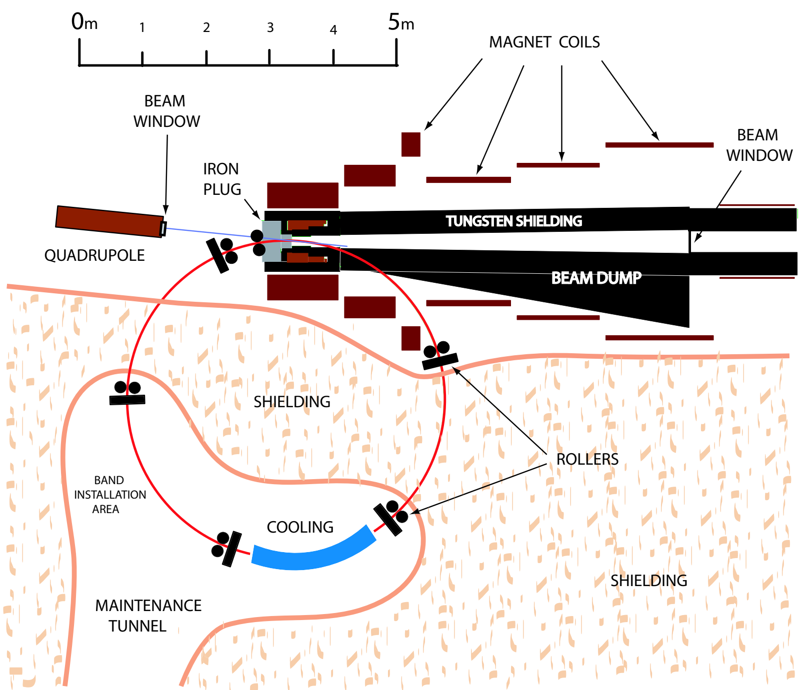
THE PARTS OF A MUON COLLIDER



This is an example footprint for the 400 GeV muon collider parameter set . Figure taken from the joint write-up for the 6-month study.

TARGETRY

- slated as the “other” main challenge (with cooling) for generic muon colliders in, e.g., 1999 APS Conference
- now looks very manageable:



King, Mokhov, Simos & Weggel,

“A Rotating Metal Band Target for Pion Production at Muon Colliders”,

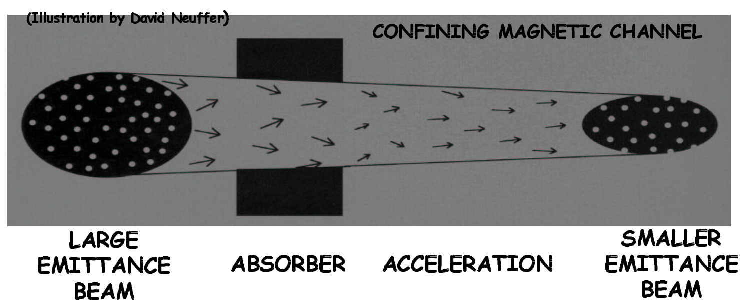
Proc. 6-Month Study on HEMC’s, available on CD at Snowmass

- in detailed MARS + ANSYS stress simulations, Ti-alloy target has von Mises stress only 10-14% of fatigue strength for multi-MW pulsed proton beam that produces 4 x 10^{12} mu/sign/bunch (~max. for muon collider parameters)
- engineers think it can be designed, built & operated

"IT'S THE COOLING"

The high-performance ionization cooling channel is the signature technology and dominant technical challenge for muon colliders.

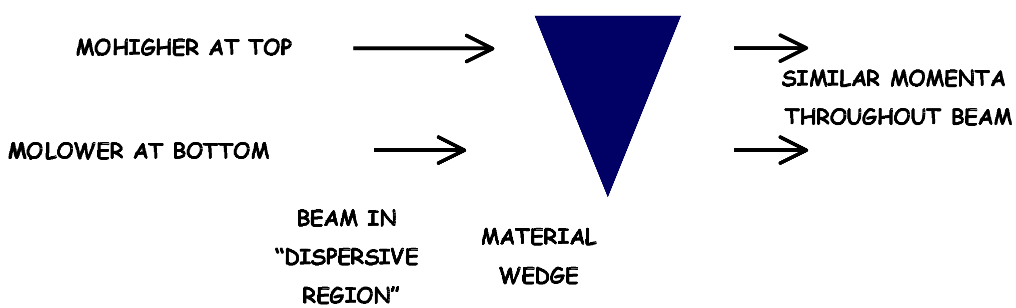
Simple concept:



However, Coulomb scattering and energy straggling compete with cooling,

A) confines cooling to a difficult region of parameter space (low energy, large angles)

B) need to control beam energy spread to obtain required ~10^6 reduction in 6-D phase space:



"emittance exchange"

We have:

a) general theoretical scenarios & specs. to reach the desired 6-D emittances

b) detailed particle-by-particle tracking codes (modified GEANT,ICOOL) & (new) higher order matrix tracking code (modified COSY-infinity) + (new) wake field code interface

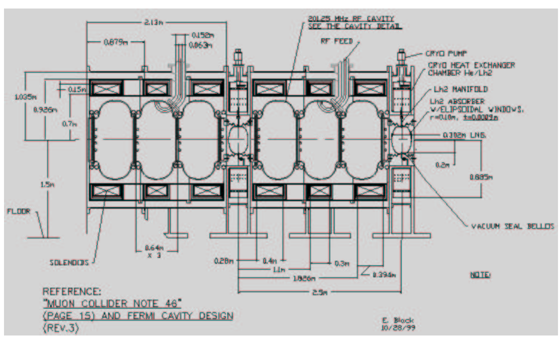
c) engineering designs of pieces

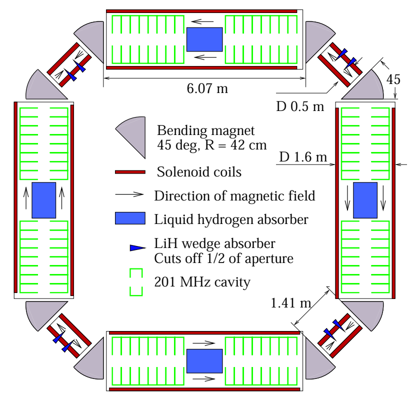
d) neutrino factory designs for factor of ~10 *transverse* cooling

e) "ring cooler" design for MUCOOL expt. with predicted full 6-D cooling by factor of ~32

(c.f. muon collider needs ~10^6 ~ 32^4)

2 sub-units of a cooling stage (Black, IIT)





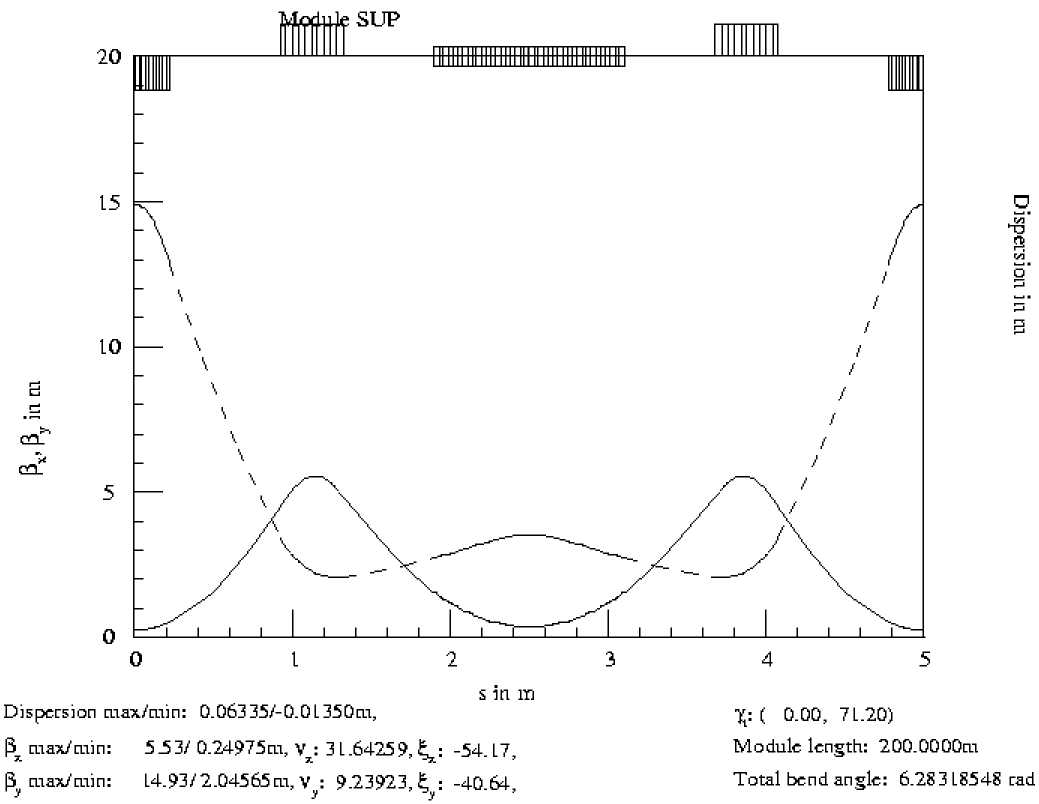
"ring cooler"

(Balbekov, FNAL)

But we have yet to put the pieces together to "build the muon collider cooling channel on a computer" => This is our #1 item of business

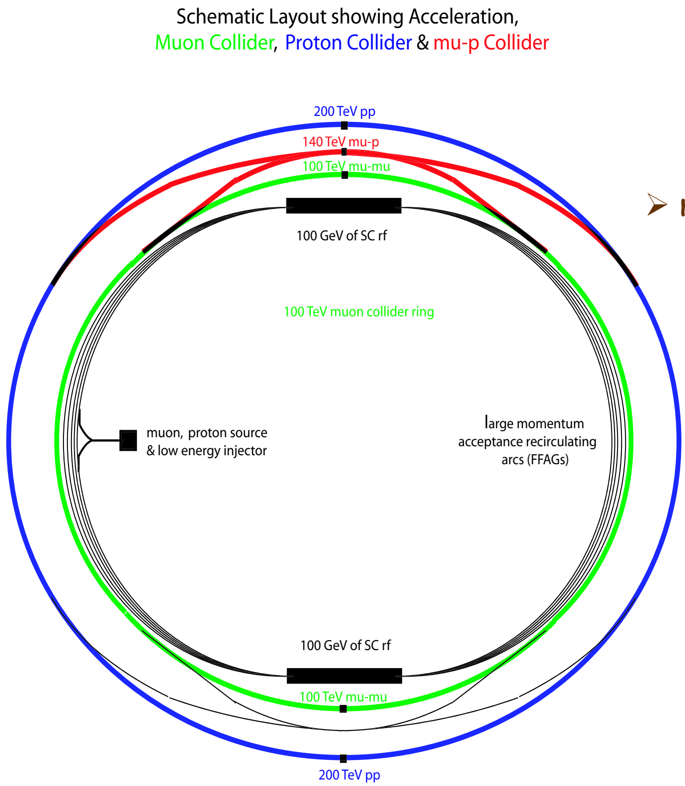
ACCELERATION IN FFAGs

Acceleration will be the main cost driver for VLMCs. Cost reduction => acceleration in (e.g.) FFAG lattices. (Lattices of SC+fast-ramping magnets are also under consideration - Summers, Palmer.)



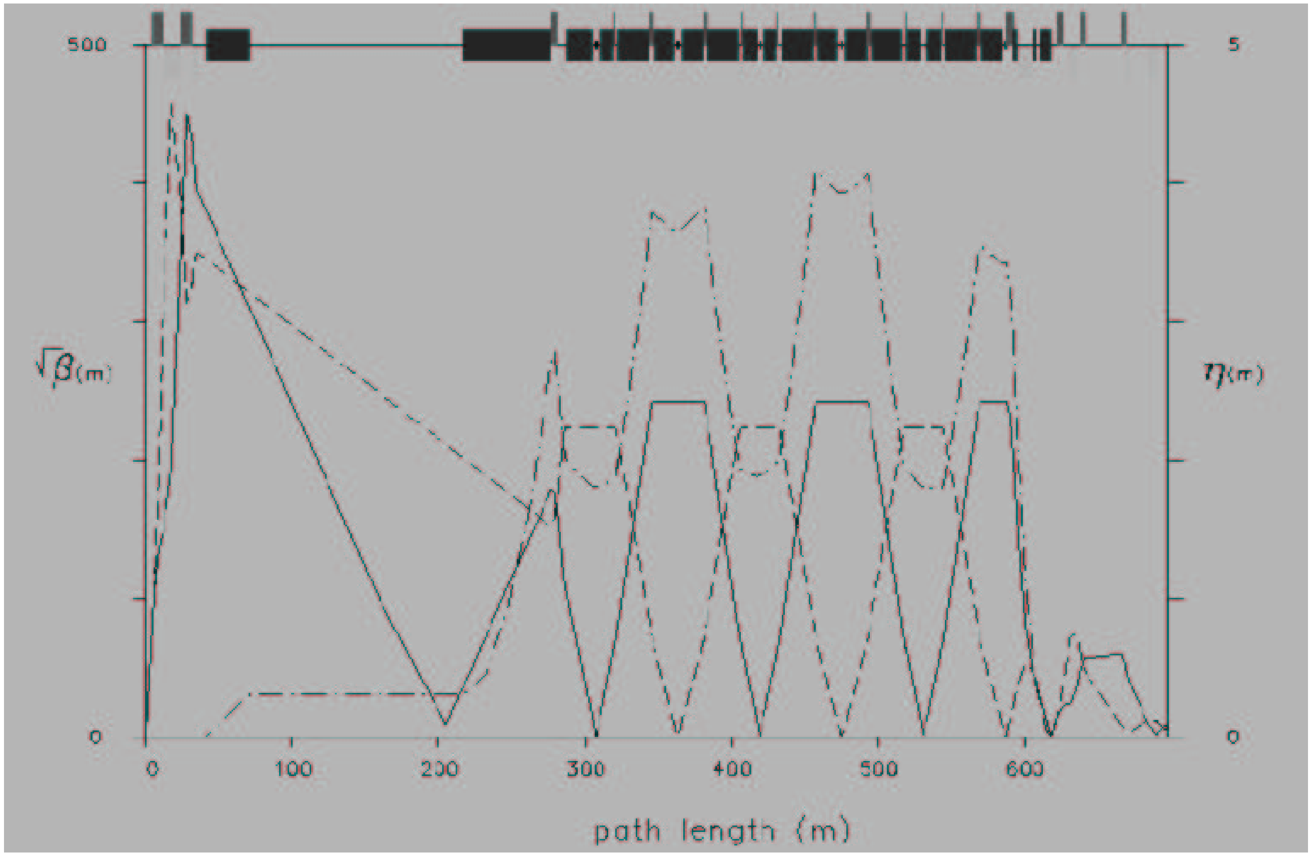
The figure shows a module of an FFAG lattice for 10->20 GeV by Trbojevic (+ Courant & Garren). Trbojevic expects such FFAG lattices to work well at very high energies (work in progress - we will know soon).

ACCELERATION STRATEGY



- ~200 GeV/turn of SC rf cavities, matched to beam for high efficiency
  - 50 TeV/200 GeV => 250 passes
  - Padamsee calculated 53% (10 TeV) or 33% (100 TeV) efficiencies for HEMC'99 parameters
- multiple recirculating arcs of FFAGs, each providing a factor of 2+ in energy
  - all arcs have same transit time => matched to rf
  - 1000 ~ 2^{10} => 10 FFAG arcs, or less
  - fractional decay loss for 100 GeV -> 50 TeV/beam ~ e^{-1} => need 1.9e12 -> 0.7e12 muons (OK)

COLLIDER RING



The design of the final focus is a major challenge for energy frontier muon colliders.

The figure shows an existing 4 TeV final focus design by Johnstone & Garren (beta*=3 mm). Impressive new 30 TeV ff now exists (Raimondi, beta*=4.8 mm)

MAGNET REQUIREMENTS

- similar to VLHC: collider ring magnets are only 1/2 the field and may be single aperture, but the final FFAG ring will require stronger magnets than this

- crucial to remove all heat from decays (~40 MW) and synch. rad. (~40 MW) at room temperature => need mid-plane with no cryostat or other solution

- much room for common R&D

COLLIDER RING MAGNET COSTS μ

Slides from Mike Harrison (BNL)

"Magnet Challenges: Technology and Affordability"

HEMC'99 Workshop,

Montauk, NY, Sept'99

Affordability

- RHIC Dipoles 8cm, 10m, 4T, FY95 cost $110K each
- HEMC Dipole
  - 8cm -> 15cm 50%
  - 4T -> 7T 50%
  - 10m -> 15m 40%
  - FY95 -> FY00 15%
  - Estimate HEMC Dipole $400K or $26K/m based on RHIC
- 10 Tev needs 15km circumference -> magnet costs ~$400M. Ring costs = dipoles x 3(or4) = $1.2(6)B (probably a lower bound since HEMC dipoles are more complex than RHIC)

ENCOURAGING!

Caveat: collider ring only; acceleration may be a few times this.

Conclusions

- A 10 Tev machine based on Nb-Ti magnets (7T dipole) is challenging but possible
- A 100 Tev machine does not look feasible based on 10T cosine theta dipoles
- A different magnet design (no mid plane cryogenics) would help
- Newer technologies (Nb3Sn, HTS) would be beneficial assuming that costs are reasonable and they work

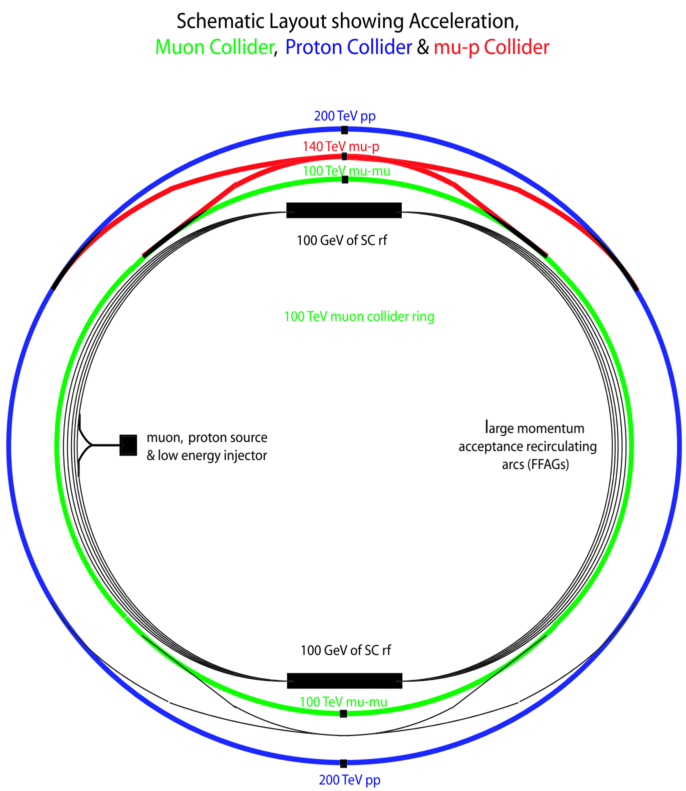
MU-P COLLIDER OPTION

- will need mu & p path lengths exactly same

- detector design challenging

- better to use bigger proton bunches - matched to muon bunches. Can this be done?

1/2-ENERGY VLHC INJECTOR



- accelerate trains of proton bunches with same total charge as muon bunch train => matched to rf with no extra work

- smaller bunch charges => don't expect stability problems

- do enough trains to fill one proton ring, then reverse FFAG magnets so can inject into ring with opposite sense

CONCLUSIONS

- the idea looks promising at first glance
- what are the accelerator issues?